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Some methodological considerations on Delta distribution, stratification and tow duration, for trawl surveys carried out in West Africa

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ABSTRACT

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Trawl surveys carried out in West Africa, particularly off the Senegalese coast, have stimulated methodological studies. The use of Delta distribution analysis generally increases the values of standard mean and variance parameters. A prior stratification of sampling does little to reduce the variance of the total catches, or of the main species catches. Optimal allocations of the number of hauls per stratum vary a great deal from one survey to another. A trawl tow duration of 30 min is sufficient for abundance estimations.

INTRODUCTION

The tropical coastal waters of West Africa are inhabited by fish communities which have a very wide distribution, from Mauritania to Angola (Longhurst, 1969). A single 1 h trawl tow provides fishes belonging to numerous species, a dozen of which can be found in significant quantities.

Groundfish surveys are particularly important in West Africa as commercial fishing statistics are generally unreliable and incomplete, and do not provide sufficient information on the quantitative composition of stocks and their dynamics. Several trawl surveys have been carried out in recent years, based on stratified random sampling in Mauritania, Senegal, Guinea, the Ivory Coast, Togo and Benin (Girardin, 1987; Caverivière and Thiam, 1992; Domain, 1989; Caverivière, 1989; Lhomme, 1985; Vendeville, 1990). The trawl surveys in Senegal enable us to study some methodological aspects of the sampling scheme, and the mean and variance calculations. Some results are com-

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pared with those from the Ivory Coast. Specific studies were also made on the effects of tow duration.

METHODOLOGICAL PRESENTATION OF SURVEYS MADE IN SENEGALESE WATERS

Prospection surveys for demersal fish resources on the Senegalese continental shelf have been carried out regularly since 1986, by stratified random sampling. The shelf between the 10 and 200 m isobathes was divided into 1150 rectangles, each with 2′ longitude and 2.5′ latitude sides. This last distance is consistent with a standard tow of 30 min duration. The rectangles were then allotted to three geographical areas and four bathymetric bands. The different combinations formed twelve strata. The three areas (Fig. 1) were: (1) Northern: from the Mauritanian border to Dakar; (2) Central: from Dakar to the northern border of Gambia; (3) Southern: from the southern border of Gambia to Cape Roxo (southern border of Senegal).

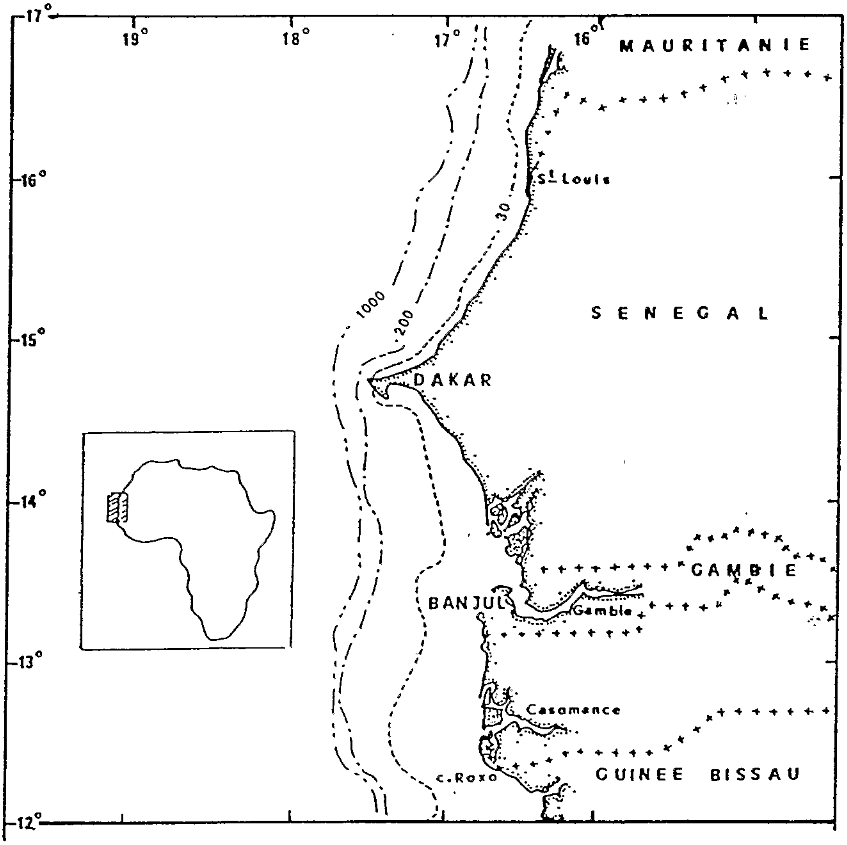

Fig. 1. Location of the principal survey area.

The four bathymetric bands were chosen in the light of prior studies on the distribution of main species. They were defined by the 10–30, 30–60, 60–100, 100–200 m isobathes; the last is very small in the central and southern areas where trawling is very difficult.

One rectangle out of ten in each stratum was chosen at random for trawling. The number of trawl tows in each stratum ranged from 3 to 41.

The stratified random sampling design is used to reduce estimation variance in comparison with non-stratified random sampling, when strata have been appropriately chosen (Cochran, 1977; Grosslein and Laurec, 1982).

The weighted mean ($\bar{x}$) was computed according to the surface area per stratum

$$\bar{x}=\frac{1}{A}\Sigma A_i\bar{x}_i$$

where A_i represents the surface of stratum i and A is the total surface. Its variance is

$$s^2(\bar{x})=\frac{1}{A^2}\Sigma A_i{}^2 s^2(\bar{x}_i)$$

$s(\bar{x}_i)$ is the mean standard error for stratum i.

Seven surveys were carried out from October 1986 to April 1990; four during the cool season (February–April) and three during the end of the hot season (October–November). The 100–200 m stratum was not sampled at every site, because of trawling difficulties.

COMPARISON BETWEEN MEANS AND STANDARD DEVIATIONS COMPUTED FROM NORMAL DISTRIBUTION AND DELTA DISTRIBUTION

Relative abundance indices and their variances derived from trawl surveys were often estimated in the past from standard mean and variance calculations. This method will be referred to as Normal in comparison with those in use for particular distributions. For a given species, hauls generally show an irregular distribution with many zero values and some very large catches. Presently, the Delta distribution system of analysis seems best suited to increase the efficiency in mean and variance calculations for trawl surveys (Pennington, 1983 and 1986). Delta distribution treats positive values separately on the assumption that they have a simple log-normal distribution, then the zero values are included. A hyper-geometric function, which can easily be computed, is used. The efficiency of Delta distribution depends on the number of trawl tows, on the proportion of zero values and on the variability range for positive values (Smith, 1988).

Delta distribution means (Table 1) for the seven surveys combined are

TABLE 1

Means (per 30 min) and coefficients of variation computed by Delta distribution (surveys conducted, $n=7$) for the grand total and for the twenty main species and groups of species on the Senegalese continental shelf (10–100 m), differences with Normal values and differences in percentage compared with these values

	% No.[1]	Delta mean	Mean diff.	% Mean diff.	Delta CV	CV diff.	% CV diff.
Brachydeuterus auritus	58.8	94.8	40.3	+73.9	46.1	18.3	+65.8
Trachurus+decapteru	56.7	81.1	14.2	+21.2	33.9	8.2	+31.9
Dentex angolensis	76.1	73.5	21.2	+40.5	56.0	18.7	+50.1
Pagellus bellottii	39.7	32.3	7.8	+31.8	28.4	6.7	+30.9
Boops boops	74.2	31.8	12.1	+61.4	54.5	7.2	+15.2
Chloroscombrus chrysurus	78.6	25.7	8.0	+45.2	61.1	11.4	+22.9
Selacian group	14.7	19.9	−3.2	−13.9	22.4	−4.9	−18.0
Cymbium spp.	71.7	16.4	0.9	+5.8	35.2	5.3	+17.7
Galeoides decadactylus	76.9	12.4	2.8	+29.2	51.7	9.7	+23.1
Dactylopterus volitans	64.9	11.3	−0.6	−5.0	42.8	−0.8	−1.8
Dentex congoensis + *D. macrophtalmus*	94.3	8.4	−0.2	−2.3	72.4	4.4	+6.5
Pomadasys spp. *(-incisus)*	71.4	7.7	−0.3	−3.8	37.8	0.7	+1.9
Pteroscion peli	87.1	7.0	0.7	+11.1	42.9	2.5	+6.2
Arius spp.	76.2	6.8	0.8	+13.3	38.1	4.6	+13.7
Sparus caeruleostictus	63.4	6.3	1.7	+37.0	39.4	10.9	+38.3
Plectorhynchus mediterraneus	70.7	5.0	0.1	+2.0	35.8	1.6	+4.7
Scomber japonicus	82.3	4.9	−1.1	−18.3	51.0	−0.7	−1.4
Pseudotolithus spp.	80.5	4.9	0.8	+19.5	36.1	8.5	+30.8
Epinephelus+Mycteroperca	55.8	4.9	0.3	+6.5	26.8	3.1	+13.1
Acanthurus+Balistes	76.5	4.3	1.0	+30.3	44.5	7.9	+21.6
Grand total catches	0.0	450.9	21.0	+4.9	14.6	2.3	+18.7

[1]Zero value percentages.

generally higher than Normal means, up to 74% for the bigeye grunt (*Brachydeuterus auritus*), which is the most common species. But means can also be below Normal. Coefficients of variation (CV) are also generally higher than with Normal. Pennington (1983) noted that Normal distribution underestimated the true mean variability and therefore gave an over optimistic impression of the accuracy of a given survey. The range of the differences when means and CV are computed with Normal or with Delta distribution depends on the proportion of zero values, but not exclusively (repartition of positive values). The eurybathic species *Pagellus bellottii* (red pandora), which has few zero values, generally shows a great difference. By contrast, the coastal species *Pteroscion peli* and the deep water Dentex *D. congoensis* and *D. macrophtalmus* show many zero values and relatively small differences. The all-species catches, which have no zero values, have a 4.9% positive difference for the mean and 18.7% for the CV between Delta and Normal distributions.

Table 2 shows, for three species, the same results as those presented in Table 1, but for each survey. On the whole, *Brachydeuterus auritus* has the highest positive differences, the selacian group (sharks and rays) the highest negative differences and the grunt (*Pomadasys jubelini, P. peroteti* and *P. rogeri*) an intermediate 'species'. For each survey, the differences are always positive for *B. auritus*, with means and CV that can double or more. The difference values can be positive or negative, depending on the surveys, for the other two species.

From data on eleven trawl surveys off the Ivory Coast, Bernard (1990)

TABLE 2

Means (kg per 30 min) and coefficients of variation computed by Delta distribution per survey for three species, difference with Normal values and difference in percentage compared with these values

Surveys	Delta mean	Mean diff.	% Mean diff.	Delta CV	CV diff.	% CV diff.
Brachydeuterus auritus						
LS8614	66.6	16.2	+32.3	37.3	12.8	+52.2
LS8709	185.6	97.4	+110.4	41.6	17.7	+74.1
LS8717	74.5	17.6	+30.9	32.4	9.2	+39.7
LS8806	127.5	61.2	+92.2	45.8	14.7	+47.3
LS8905	134.6	74.9	+125.3	64.0	31.7	+98.1
LS8912	47.4	1.6	+3.4	33.6	1.6	+5.0
LS9002	27.2	14.2	+109.2	67.7	40.5	+148.9
All LS	94.8	40.4	+73.9	46.1	18.3	+65.8
Selacian group						
LS8614	24.4	−1.3	−5.1	15.8	−4.2	−21.0
LS8709	17.1	3.9	+29.1	26.8	8.9	+49.7
LS8717	36.2	−24.4	−40.3	39.2	−30.5	−43.8
LS8806	15.7	−0.6	−3.4	21.5	−7.1	−24.8
LS8905	12.3	0.9	+7.4	16.3	4.5	+38.1
LS8912	19.1	0.7	+3.8	21.6	−1.6	−7.0
LS9002	14.2	−1.3	−8.1	15.3	−4.2	−21.5
All LS	19.9	−3.2	−13.9	22.4	−4.9	−18.0
Pomadasys spp. (-P. insicus)						
LS8614	8.4	1.1	+14.3	39.5	12.3	+45.2
LS8709	7.6	0.2	+2.0	38.0	−2.4	−5.9
LS8717	5.7	0.2	+3.6	31.1	−1.6	−4.9
LS8806	11.2	2.0	+21.7	36.2	8.7	+31.6
LS8905	3.3	0.1	+1.5	32.0	3.5	+12.3
LS8912	15.3	−5.7	−27.1	53.2	−15.2	−22.2
LS9002	2.3	−0.1	−2.1	34.9	−0.7	−2.0
All LS	7.7	−0.3	−3.8	37.8	0.7	+1.9

made the same calculations for the six main continental shelf species. In comparison with the use of Normal distribution, Delta distribution would reduce the CV by half, on average, for the six species, whereas for the five species common to both studies (*Galeoides, Pomadasys, Brachydeuterus, Pseudotolithus, Pagellus* and *Dentex*), the CV increases off Senegal. Bernard noted, with reference to Smith (1988), that Delta distribution using this conventional method underestimates the mean variance when sample numbers are small. This is the case in Ivory Coast waters where the number of hauls per stratum is generally much less than in Senegalese waters.

For the all-species catches, the average CV is 12.3% with Normal distribution (skewed) and rises to 14.6% with Delta distribution. The last result is quite satisfactory for trawl surveys (Grosslein and Laurec, 1982). The CVs for the all-species catches per tow (10–120 m) are similar in the Ivory Coast, with 12.2% on average (Normal distribution) for three surveys (Caverivière, 1982 and 1989). The sampling scheme used was the same as in Senegalese waters, that is, one rectangle out of ten was selected by stratified random sampling.

With Normal calculation the 20 primary species of Table 1 represent 75–87% (varying with the surveys) of the grand total. When Delta distribution is used, the sum of the mean catches for these species is often higher than the grand total catches computed separately for the all-species as a whole. In this way, the sum of the Delta means per species in Table 1 represents 102% of the grand total catches (129% for Survey LS8905). This highlights an important problem linked with the use of Delta distribution: the sum of the species catches per tow is not equal to the whole, all-species catches per tow. This problem does not seem to have been pointed out in earlier studies on the subject.

STRATIFICATION AND THE VARIANCE OF ESTIMATIONS

Effects of stratification used

Stratification is used to reduce the variance of estimations compared with non-stratified random sampling, when strata have been appropriately selected (Grosslein and Laurec, 1982). In areas of high species diversity, as on the west African continental shelf, it is difficult to select prior strata that present a satisfactory design for most species. The stratifications generally used are related to the shape of the continental shelf, in areas perpendicular to the coast and in bathymetric bands assumed to contain the species belonging to the different communities: coastal species, intermediate species and deep continental shelf species. In Senegalese waters, nine strata were defined between 10 and 100 m. What are the modifications of the mean variances when calculations are carried out for several levels of stratification, or without stratification?

For the all-species catches, the CVs computed by Delta distribution show differences in their variations according to the survey and according to the stratification level (Table 3). Thus, for nine strata, stratification reduces the CV from 15.3% to 9.8% in the LS8709 survey, but, paradoxically, CV increases from 16.1% to 20% in the LS8614 survey. On average, for the seven surveys, stratification in nine strata reduces the average CV by 0.9%; stratification with three depths does not lead to a precision gain; stratification in three zones reduces CV by 1.3%. Therefore, stratification seems to be of little relevance to all-species catches. This means that variability within a stratum is as great as or greater than variability between strata; according to the depth, but also according to the area, some species compensate for others.

For catches by species, Table 4 shows the CVs obtained from Delta distribution for the 14 main species, according to nine strata and without stratification. Stratification sometimes produces important CV reductions, but for 11 of the 14 species, there is a negative effect of stratification for at least one survey. For the three remaining species, CV reductions range from 23% to 34% of non-stratified CV, for a coastal species *Pteroscion peli* and two more eurybathic species, the red pandora *Pagellus bellottii* and the Carangidae *Trachurus trachurus* and *Decapterus*. Other species regarded as coastal, deep or eurybathic do not show such precision gain, so no rule can be laid down. On the whole, stratification leads to a slight loss for two species.

Similar results, giving little or no CV reduction with the use of stratification (Normal distribution), were found on the Ivory Coast (Caverivière, 1982, 1989) for all-species catches and for both primary species, the bigeye grunt *Brachydeuterus auritus* and *Balistes carolinensis*.

TABLE 3

Coefficients of variation of the grand total mean (10–100 m) per survey for three stratification levels, and precision gains (CV reductions) compared with non-stratified values

Strata	Grand total CV (10–100 M)							% CV reduction
	LS8614	LS8709	LS8717	LS8806	LS8905	LS8912	LS9002	
9 3 areas, 3 depths	20.0	9.8	14.8	13.8	15.3	15.2	13.3	0.9
3 3 depths	23.9	12.8	13.8	14.8	14.3	14.5	14.2	0
3 3 areas	15.7	10.1	14.2	12.9	14.9	15.7	15.9	1.3
1 Senegal 10–100 m	16.1	15.3	14.7	15.1	14.9	15.5	16.8	–

TABLE 4

Coefficient of variation per survey for the main species with and without stratification, and average CV reductions (in value and in percentage)

	Strata	Surveys							% CV reduction
		LS8614	LS8709	LS8717	LS8806	LS8905	LS8912	LS9002	
Brachydeuterus auritus	9	37.3	41.6	32.4	45.8	64.0[1]	33.6	67.7[1]	6.6
	1	42.8	52.8	59.9	53.4	53.6	52.1	54.1	12.5[2]
Trachurus+*Decapterus*	9	51.5	27.1	38.1	23.4	37.5	34.7	25.2	17.2
	1	70.5	46.5	55.5	42.1	47.2	54.1	41.8	33.7[2]
Dentex angolensis	9	62.2	38.5	89.8[1]	49.9	40.2	79.6[1]	31.5	−0.9
	1	77.6	45.2	65.5	54.1	41.4	65.1	36.8	−1.6[2]
Pagellus bellottii	9	39.9	21.6	22.1	22.5	38.0	36.7	18.0	8.4
	1	47.3	39.2	39.1	29.5	38.1	38.1	26.0	22.7[2]
Boops boops	9	40.9	41.1	81.7[1]	52.3	60.9[1]	65.5[1]	38.9	6.5
	1	91.1	49.3	66.3	58.8	55.0	56.7	49.7	10.7[2]
Chloroscombrus chrysurus	9	74.4[1]	53.1	48.1	69.9	78.6[1]	48.6	54.9[1]	7.1
	1	66.5	53.7	53.6	76.6	74.2	63.0	53.3	11.3[2]
Cymbium spp.	9	28.6	36.4	48.4	21.3	40.1[1]	44.9[1]	26.7	3.2
	1	39.9	37.1	53.0	21.7	44.0	43.3	29.9	8.4[2]
Galeoides decadactylus	9	41.3	55.2[1]	54.1[1]	39.8	42.6	34.4	94.5[1]	0.3
	1	45.6	47.8	50.8	40.1	57.9	45.9	76.1	0.6[2]
Dactylopterus volitans	9	47.5	31.3[1]	73.7[1]	27.7	42.0[1]	41.4	36.1	−3.1
	1	52.1	31.2	39.4	28.5	34.8	51.4	40.8	−7.7[2]
Dentex congoensis+	9	62.0	44.6	100.0[1]	38.2	100.0	71.4	90.5	0.9
D. macrophtalmus	1	74.9	51.4	68.5	44.8	100.0	81.9	91.7	1.3[2]
Pomadasys spp.	9	39.5	38.0[1]	31.1[1]	36.2	32.0	53.2[1]	34.9	2.7
(-*P. incisus*)	1	47.5	36.3	30.8	41.9	42.8	47.7	37.1	6.8[2]
Pteroscion peli	9	40.3	35.1	45.2	44.2	51.7	33.1	50.4	13.7
	1	44.9	83.3	54.2	51.5	60.9	39.8	61.0	24.2[2]
Arius spp.	9	32.6	47.5[1]	30.5	31.5	32.6	35.6	56.2	3.5
	1	43.1	43.6	33.3	37.0	35.8	39.5	58.6	8.4[2]
Sparus caeruleostictus	9	34.3	52.7[1]	25.1	25.9	68.5[1]	36.4	32.6	0.4
	1	43.4	40.0	36.3	31.1	50.9	41.4	34.9	0.9[2]

[1]CV after stratification, if it is higher than non-stratified CV.
[2]%CV reduction.

Optimal allocations

One basic rectangle out of ten was arbitrarily chosen to be sampled for each of the selected strata. Consequently, the sampling effort was allocated only on the basis of the surface covered by the stratum. This process is recommended (Grosslein and Laurec, 1982) when previous information on the inter-strata variances is not available. After completing a survey, it is possible to calculate the way in which the total number of hauls could have been distributed between the strata in order to reduce the final variance in the total area. In general, optimum allocation is obtained by allocating to each stratum a sample

TABLE 5

Optimal allocation of trawl tows per stratum for each survey

Area		Northern			Central			Southern		
Depth (m)		10–30	30–60	60–100	10–30	30–60	60–100	10–30	30–60	60–100
Allocation used		8	7	10	14	13	10	21	13	3
Optimal allocation	LS8614	3	1	45	7	7	15	14	7	0
	LS8709	8	12	19	13	14	11	16	4	3
	LS8717	5	10	5	35	3	16	22	2	1
	LS8806	9	6	12	12	8	8	40	2	1
	LS8905	12	8	10	36	6	10	8	3	7
	LS8912	4	7	4	12	7	10	23	9	23
	LS9002	9	3	31	12	4	23	3	6	8
	LS Mean	7.1	6.7	18.0	18.1	7.0	13.3	18.0	4.7	6.1

proportional to the product of its surface (A_i) by the intra-stratum standard error (s_i)

$$n_i = \frac{N s_i A_i}{\Sigma s_i A_i}$$

For the seven surveys conducted off the Senegalese coasts, optimal allocations per stratum were computed in this way from all-species catches (Table 5). It is to be noted that results vary a great deal from one survey to another, even when surveys are carried out in the same hydrological season. Thus, from Delta distributions based on 99 total hauls, the optimum allocations computed for the northern 60–100 m stratum vary from 4 hauls (LS8912) to 45 hauls (LS8614), 3–40 hauls for the southern 10–30 m stratum and from 7 to 36 for the central 10–30 m stratum. It would seem wise, on the whole, to reduce the allocations used on the 30–60 m strata and to increase those used on the 60–100 m strata. The allocations in use, however, are often close to the average optimal allocations computed and, considering the variability of values, it seems preferable to keep the current allocations for future surveys.

PROPORTIONALITY OF CATCHES BETWEEN 30 MIN AND 1 H TOW DURATIONS

The problem

Trawl surveys are often carried out with standard 30 min tows. This offers several advantages compared with longer tows: (i) a greater number of tows can be made in one day, which will reduce the duration of a survey when the number of tows has been pre-established; (ii) quantities to be sorted out will be reduced; this will save time for the men in charge and could lead to having fewer men on board and/or more time for biological sampling.

One possible drawback could stem from fish behaviour while a trawl is operating. Direct observations have repeatedly shown that many species swim in the mouth of the trawl for some time, until fatigue sets in. This time spent swimming may depend on the species and on individual size. Wardle (1986) noticed that larger fish, such as adult saithe (*Pollachius virens*), cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), can swim for hours in the mouth of the trawl. If we assume that adults belonging to an evenly distributed species can swim for 15 min in the mouth of the trawl, a 30 min tow duration will only catch half the individuals present on the passage of the trawl, whereas a 1 h trawl tow will catch three out of four. There will be no direct proportionality between tow durations and catches. On the other hand, if there is direct proportionality, it will be possible to assume that a 30 min tow is at least as good for sampling a population as a 1 h tow.

Data

An important sampling effort was made able because of what is known about strong intrinsic variations in abundance (random variations when conditions were unchanged in other respects; Caverivière, 1982). The data consist of 65 pairs of 30 min and 1 h trawl tows. Each pair of tows was carried out at the same site, mid-tows overlapped and trawl directions were the same. The 30 min and 1 h tows were alternated to avoid the effects of possible ground deterioration after the first tow.

The 65 pairs of tows were made during eight research trips conducted by two vessels using two different trawls (a high-opening model and an Irish model), between January 1987 and April 1989. All the tows were carried out during daylight. Trawl speed was about 3.7 knots for both trawlers. The distribution of trawl pairs according to depth ranged from 18–19 m to 120 m.

Processing and results

The use of ratios seems suited to the data (Cochran, 1977; Frontier, 1983). The ratio estimate $\hat{R}=\bar{y}/\bar{x}$ (1 h catch mean/30 min catch mean) has a variance which can be approximated if the number of pairs n is more than 30 (below this, the approximation used is unsuitable and bias becomes too great).

$$v(\hat{R})=\frac{\Sigma y^2-2\hat{R}\Sigma xy+\hat{R}^2\Sigma x^2}{\bar{x}^2(n-1)n}$$

If value 2 is included within the 95% confidence limits of the ratio estimate, we can conclude that the 1 h catches are not significantly different from twice the result of 30 min catches, and that the latter are sufficient for abundance estimations.

$$\hat{R}-1.96\sqrt{v(\hat{R})}<\hat{R}<\hat{R}+1.96\sqrt{v(\hat{R})}$$

The results for the all-species catches and for the main species are given in Table 6. Double absences for a species in a pair of tows were not used for the determination of the n value, because trawling did not take place in the distribution area of the species. A preliminary study showed that the separate $\hat{R}$ values for the two vessels were close, therefore the results for the two different trawls were grouped.

Only 3 'species' out of 23 do not include the value 2 in the 95% confidence limits of the ratio and these values are subject to bias because $n<30$. The ratio estimate for the all-species catches (1.95) is very close to 2; a similar ratio estimate (1.96) was computed by Barnes and Bagenal (1951) in the north-west Atlantic for the same durations. In the north-east Atlantic, Pennington and Grosslein (1978) showed that 15 min tows caught proportionately as many eel pout and haddock as 2 h tows.

TABLE 6

Means and ratio estimate ($\hat{R}$) with its 95% confidence limits for n pairs of 1 h (y) and 30 min catches (x) of the main species

Species	n	$\bar{y}$	$\bar{x}$	$\hat{R}$	$\hat{R} \pm 1.96$ SD	
Grand total	65	820.4	420.7	1.95	1.60	2.30
Trachurus spp.	49	183.7	76.8	2.39	1.49	3.29
Decapterus rhonchus	19	32.0	15.2	2.10	(0)	(4.73)
Scomber japonicus	14	8.2	8.9	0.92	(0)	(2.72)
Boops boops	38	244.4	106.4	2.30	1.08	3.52
Brachydeuterus auritus	28	78.8	62.7	1.26	(0.91)	(1.61)
Sphyraena spp.	22	9.7	2.9	3.32	(1.75)	(4.89)
Dactylopterus volitans	26	102.1	61.5	1.66	(1.17)	(2.15)
Pagellus bellottii	52	82.4	45.1	1.82	1.31	2.33
Sparus caeruleostictus	32	23.6	13.7	1.73	1.36	2.10
Dentex canariensis	39	7.7	4.6	1.66	1.13	2.19
Dentex angolensis + *D. macrophtalmus*	29	189.9	132.1	1.44	(0.54)	(2.34)
Epinephelus aeneus	47	9.9	4.9	2.03	0.99	3.07
Total groupers	50	11.9	7.1	1.69	0.95	2.43
Pseudupeneus prayensis	41	16.5	8.7	1.89	1.28	2.50
Priacanthus arenatus	26	142.7	40.4	3.53	(3.10)	(3.96)
Plectorhynchus mediterraneus	30	19.8	8.1	2.44	1.56	3.32
Umbrina canariensis	27	6.2	1.6	3.93	(0)	(9.20)
Pseudotolithus spp.	14	9.4	8.0	1.18	(0.69)	(1.67)
Zeus faber	46	6.7	3.1	2.14	1.30	2.98
Raja miraletus	56	7.7	4.7	1.62	1.23	2.01
Mustelus mustelus	21	38.1	13.6	2.81	(1.40)	(4.22)
Sepia spp.	55	7.8	3.5	2.22	1.49	2.95

SD, standard deviation.
Values in parentheses, skewed: $n < 30$.

In order to have over 30 pairs in each stratum, the all-species data were arbitarily divided into two depth strata: 18–44 m and 45–120 m (Table 7). The ratio estimate is smaller in the coastal fishing grounds than in the deeper grounds. Considering that the confidence intervals overlap, the two values are not significantly different. The value 2 is included in these intervals.

It is rather difficult to justify a ratio estimate of <2 between 1 h and 30 min trawl tows, except in the case of trawl saturation when the fish already in the trawl restrain further catches. A test was carried out to see if such a saturation could be found with the data. To do this, the data were divided (Table 8) into two series: one for which the sum of catches per pair was <1000 kg (lowest value = 113 kg), and the other for which this sum was greater than 1000 kg (highest value = 5758 kg). The ratio estimate is the same for both

TABLE 7

Ratio estimates and their confidence limits for n pairs of 1 h (y) and 30 min (x) total catches, according to 2 depth strata

Ratio parameters	Strata	
	18–44 (m)	45–120 (m)
n (Pairs of tows)	33	32
$\bar{y}$ (1-h tows)	804.5 kg	836.4 kg
$\bar{x}$ (30 min tows)	449.9 kg	390.7 kg
$\hat{R}$ (Ratio-estimate)	1.79	2.14
95% Confidence limits	$1.44<R<2.14$	$1.52<R<2.76$

TABLE 8

Ratio estimates for n pairs of 1 h (y) and 30 min (x) total catches, according to 2 catch levels

Ratio parameters	$\Sigma x+y$ (per pair)	
	<1000 kg	>1000 kg
n (Pairs of tows)	36	29
$\bar{y}$ (1-h tows)	297.4 kg	1469.5 kg
$\bar{x}$ (30 min tows)	152.3 kg	754.0 kg
$\hat{R}$ (Ratio-estimate)	1.95	1.95

series and very close to value 2. There is no evidence of trawl saturation in the range of values for total catches covered by the study.

In addition, large individual fish, with a high swimming capacity, were caught in the same proportion by 30 min tows and 1 h tows. Among the larger species, the white grouper *Epinephelus aeneus* was the only species regularly present in the pairs of tows ($n=47$). The ratio estimate is 2.0 and the larger individuals of this demersal species are equally well sampled with 1 h or 30 min tows. Large barracuda (*Sphyraena afra*), over 1.8 m in fork length, were caught during a 30 min tow. We should bear in mind that other pelagic species (e.g. *Trachurus* spp.), with a high swimming capacity, have a ratio estimate mainly above 2.0, although this value is included in the 95% confidence interval.

In north Atlantic waters, Godø et al. (1990) observed that 5 min tows were as effective as longer tows (>2 h), whereas a relative decrease in catch rates of large fish was expected with decreasing tow duration, since swimming capacity is dependant on size. Godø et al. suggest an interesting explanation of this discrepancy. The trawl may have a higher efficiency due to a surprise factor during the first few minutes of a tow, before a school is established, inducing an alert reaction at an earlier stage in the catch process.

CONCLUSION

The use of Delta distribution in place of Normal calculations to compute abundance estimates and their variances from trawl survey data generally increases means and their coefficients of variation. Nevertheless, the use of this distribution can be recommended because it leads to more efficient estimators of abundance. There is one disadvantage; the sum of the abundance estimates per species encountered is higher than the all-species abundance estimates computed from the total catches per haul.

When one-tenth of the basic rectangles was sampled ($3.4\ km^2$), the coefficient of variation of the all-species abundance estimate on the continental shelf in West Africa is approximately 15%. This is a very reasonable value according to studies on the subject.

Stratification of samples according to areas and depths, which is supposed to reduce variances of abundance estimates, is of little interest for all-species catches, in Senegalese or Ivory Coast waters. In the different strata, certain species compensate for others. This may be generally true in West Africa because the fish communities are the same. Stratification may be useful for some particular species, but this is not the general rule. *A posteriori* computations of optimal allocations per stratum for all-species catches vary a great deal from one survey to another, and it appears to be simpler and reasonably satisfactory to allot the sampling effort according to the stratum surface only.

The specific study of proportionality between 30 min catches and 1 h catches shows that the use of 30 min trawl tows is sufficient for abundance estimation, even for older and larger individuals. The doubling of 30 min tow results after computation by Delta distribution can be used to estimate 1 h catches for a species or group of species.

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